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15. SUPPLEMENTARY NOTES

This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration under "Pavement Faulting Study".

16. ABSTRACT

This report covers a study of grinding of PCC pavements to restore riding quality which had deteriorated due to faulting of joints. The results of the study show that grinding is a satisfactory method of restoring smoothness provided the pavement is structurally adequate. Even though faulting may recur on some projects within a few years after grinding, service life was shown to be extended a significant length of time at a cost considerably less than that of an overlay. Where an existing lane is ground and one or more new lanes added to the outside, the ground lane is expected to last as long or longer than the new lanes.

To prevent the recurrence of faulting on a ground pavement, a recommendation is made to provide a nonerodible material in the outer shoulder adjacent to the pavement.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

February 1976

FHWA D-3-32
TL No. 635167

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this interim research project report titled:

REHABILITATION OF FAULTED PAVEMENTS
BY GRINDING

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . D. L. Spellman

Principal Investigator . . . . J. H. Woodstrom

Co-Investigator . . . . B. F. Neal

Report Prepared by . . . . B. F. Neal

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

BFN:lrb

ACKNOWLEDGEMENTS

The contents of this report reflect the view of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Restoring riding quality to faulted PCC pavements is becoming a problem of increasing importance on California highways. Although the problem is not new, it has been relatively minor in the past. With the advent of the Interstate System and new requirements on alignment and structural section, many of the older pavements were abandoned or covered up. Hundreds of miles of PCC pavements were built in California during the late 1950's and early 1960's that are approaching, or have already approached, a stage of faulting that reduces riding comfort to an intolerable level. Restoration of riding quality has already started on some projects and the need on others is increasing rapidly.

Four methods of rehabilitation have been tried. One method is the application of a "skin" patch of asphalt concrete or other material to build up the lower slab at the joint to eliminate the step-off. This has proven to be a very temporary solution since the thin patches tend to ravel and break up rapidly. Also, though the step-off is eliminated, riding quality is not significantly improved.

A second method is to raise the lower slab to the level of the higher by mud-jacking. This is a very costly and time consuming operation requiring a highly skilled crew and a good degree of "luck" to get a satisfactory job. Although a faulted pavement in need of remedial treatment has fairly wide variations in measured step-off, most slabs would need raising. For instance, if joints faulted 0.10-inch or more were corrected, measurements show that about 75% of all slabs, or 250 per mile at California's joint spacing, would need mud-jacking.

A third method of rehabilitation is to apply a PCC or asphalt concrete (AC) overlay. Unless completely bonded, a PCC overlay would have to be of approximately the same thickness as the original pavement. To prevent reflective cracking and rapid deterioration, an AC overlay generally requires a minimum thickness of 4 inches. While it is usually only the outside or truck lane that needs correction, an overlay must be placed on all lanes and shoulders. This means much unnecessary work and materials use. Additionally, special consideration has to be given to drainage, ramps and structures because of the raise in profile grade.

A fourth method which has been used on a limited basis is removing the faults and smoothing the ride by grinding with diamond blades. If the pavement is structurally sound and only one lane needs correction, this appears to be an economical method of restoring riding qualities.

The study reported here was to evaluate the performance of pavements which had been ground to remove faulting.

SUMMARY AND CONCLUSIONS

The results of this study show that grinding of faulted pavements is a satisfactory method of restoring riding quality, provided that structural quality is adequate. Even though faulting may start again on some projects within a few years after grinding, service life has been shown to be extended a significant length of time at a cost considerably less than that of an overlay. (A 4" AC overlay for 2 lanes including shoulders would cost about 4 times as much as grinding 1 lane.) Where a pavement lane is ground during widening to the outside, the ground lane is expected to last as long or longer than the new outside lane since it normally receives less heavy truck traffic.

Care must be taken to prevent a polished surface when grinding. The experience of grinding contractors has shown that polishing can be prevented and an adequate skid resistance attained by placing thin spacers between the cutting blades. Although no standard spacing width has been adopted a width of 0.090-0.100 inch appears to be satisfactory.

Since free water under the pavement leads to the faulting of joints, rapid removal of this water would greatly reduce the problem. A drainage system such as the slotted pipe installation described in this report should provide adequate water removal and significantly improve pavement performance.

As a less expensive alternate, a portion of the outside shoulder adjacent to the pavement could be removed and replaced with asphalt concrete. This would eliminate a major source of fines which contribute to faulting and would also increase shoulder strength.

GRINDING PROJECTS

Experimental

The first grinding project in California, solely for the purpose of restoring riding quality to a faulted concrete pavement, was completed in 1963 on I-10 near San Bernardino. In all, 88 joints were ground with an average grinding time of 42 minutes per joint. However, on 3 of the joints, grinding time was reported to be 663 minutes, 123 minutes, and 91 minutes respectively. Considering these joints as abnormal and discarding them from the calculations, average grinding time per joint was only 33 minutes. At that rate (equivalent to about $1.40/sq. yd.), grinding was considered economically feasible and competitive in price to an AC overlay. Before grinding, the pavement had a Profile Index (PrI) of 24.6 in./mi. as determined with the California profilograph. After grinding, the PrI was 1.0 in./mi. and the pavement was considered to have excellent riding qualities*. In 1968 (5 years later), the section was still performing satisfactorily as an outside lane*. Since widening, it is now serving as an interior lane of an 8 lane freeway and has received no further treatment since the original grinding done in 1963.

Another trial was made in 1965 on SR 99, about 60 miles south of Sacramento. About 1,500 feet of the No. 2 or outside lane was ground to reduce the faulting. Although no measurements were made before grinding, data were obtained soon after grinding using the California truck-mounted profilograph. Results show that in unground areas the PrI was 11.3 in./mi., and in the ground section, was 3.7 in./mi. While 11.3 in./mi. is not considered exceptionally rough, much of the faulting roughness

*From District Memo reports.

is not reflected in the PrI since the middle 0.2 inch of roughness is blanked out when counting the roughness. The reduction is considered significant, however. Faulting at joints in the unground areas was measured at 0.10 to 0.25 inch, and zero in the ground section. While the experiment was considered successful, faulting did recur within about 2 years to approximately the same degree as adjacent unground pavement. The reason for this recurrence at such a fast rate is not understood but may be related to the character of the base and subbase. The ground area was covered a few years ago during an extensive AC overlay project.

Also in 1965, another trial pavement grinding project was completed consisting of 2,200 lineal feet of the outer (No. 3) southbound lane of SR 17 in the Bay area. Measurements before and after grinding were obtained with the truck-mounted profilograph. PrI was reduced from 21.2 in./mi. to 2.8 in./mi. Average faulting of 0.17 in. per joint (range of 0.10-0.35 in.) was reduced to zero. This section was also included in an AC overlay project a few years ago. Unfortunately no faulting measurements were made just prior to overlay so that recurrence could not be determined.

District 04 Contracts

Between 1969 and 1972, 4 grinding contracts were completed on SR17 and I-80 in the Bay area. The contracts totaled some 24 miles of PCC pavement in each direction. Although no measurements before grinding are available, the Present Serviceability Index (PSI) of each project was determined from Road Meter runs in 1975 and are shown in the following tabulation.

Co.	RT.	PM Limits	Paved	Ground	PSI - 1975	
SCl/Ala	17	18.4-24.4 & 0-1.95	1954	1971	3.60(NB)	3.10(SB)
Ala	17	10.4-15.5	1957	1972	4.30(NB)	3.95(SB)
Ala	17	15.5-21.0	1953	1969	3.40(NB)	3.05(SB)
Ala/CC	80	7.5-8.0 & 0-5.20	1956	1972	2.80(EB)	2.70(WB)

All of these projects were known to be badly faulted before grinding and to have good riding quality immediately after grinding. The section of I-80 with the lowest PSI is subjected to very heavy truck traffic and has a high water table with noticeable pumping. It is likely that further corrective action will be necessary in the near future. The PSI of each southbound section is significantly lower than that of the northbound. This is attributed to a higner level of heavily loaded trucks southbound. Although faulting is beginning to recur in some areas, all of the grinding projects are considered to have significantly improved the ride and prolonged the useful life of the pavements.

District 08 Contracts

In the southern part of the state grinding was performed as a part of 6 widening projects on I-10 completed between 1965 and 1971. The existing outside lane of some 22 miles was ground to remove faulting. (In a few areas the inside lane was also ground). On over half the mileage the ground lane is now the outside, or No. 4 lane. On the remaining portion, the ground lane is now either the No. 2 or No. 3 lane. No roughness measurements before grinding are available. The 1975 PSI ratings for the various contracts are shown in the following tabulations. Since there is no significant difference between east and west bound lanes, the results are averaged together.

Co.	Rt.	Approx. PM	Year Ground	PSI Present No. 4 Lane	Present No. 2 or No. 3 Lane
SBd	10	6-12	1965	3.10	-
SBd	10	12-18	1966	3.25	3.85
SBd	10	18-21	1967	3.35	-
SBd	10	21-24	1970	3.60	-
Riv	10	12-15	1970	-	4.25
SBd	10	4-6	1971	-	4.10

It is obvious that the useful life of these pavements has been greatly extended by grinding. The ground lanes now serving as No. 2 or No. 3 lanes are expected to have as long or longer useful life than the newer No. 4 lanes since they receive much less truck traffic. Faulting is becoming noticeable in the No. 4 lane on the earlier ground projects but is not yet at a stage requiring further treatment.

A check was also made on comparative skid resistance between ground and unground areas. No significant difference in skid numbers was found when comparisons were made on adjacent sections in the same lane. As would be expected, the values were higher on the inner lanes whether ground or not. It appears that skid resistance was not adversely affected by the grinding operation.

District 05 Contract

The latest grinding project was on US101 north of Santa Barbara completed in April 1975. The pavement was constructed in 1958. Before grinding started a survey was made which included faulting and Roadmeter measurements. Although there were a number of cracked slabs and some spalling at joints, the pavement appeared to be structurally adequate. Faulting ranged from 0.17 to 0.40-in. Averaging about 0.27-inch. The ride PSI for the 7.7 mile project (total both directions) was just under 2.50, a value usually considered terminal.

Grinding was completed in about 30 working days. A minimum of two passes was necessary at the outer pavement edge to completely remove the fault and assure some grinding on all portions of each slab. After completion of the pavement grinding, it was considered advisable to grind a portion of the AC shoulder since it was then higher than the pavement. The high shoulder was not only a possible driving hazard but also created a dam to trap runoff water. Following completion of all grinding, a joint sealant was poured into all cracks and joints (with exception of two specially treated sections as discussed below). While normally California does not seal joints except in mountain areas, it was considered desirable to use every available means to help prevent faulting from recurring. Anything that would reduce the amount of water getting under the pavement is considered helpful.

During investigation into causes of faulting, it was found that adjacent untreated shoulder material is a major source of fine material in the buildup under pavement slabs at the joints. To eliminate this source and deter further faulting, a 16-18 inch portion of the outer shoulder adjacent to the pavement was removed to a depth about 1 inch below the bottom of the pavement slab and replaced with AC. The length of this section so treated was about 1,300 feet.

On another 1,000 ft. section a portion of shoulder adjacent to the pavement was removed and a 1-1/2 inch slotted drain was placed with out-drains every 200 feet. Hopefully, water that gets under the pavement will be removed before it can contribute to the pumping action that leads to faulting. A similar installation was made previously during construction of a new 48 ft. wide pavement with out-drains spaced 100 ft. apart. Water flow from the drains was measured during and immediately after a moderate rain, and found to average about 60 gal./hr. (from all drains). Two of the drains were flowing over 100 gal./hr. Flow stopped within 2 hours after the rain stopped.

A final survey after completion of work on the old pavement indicated that all faulting was corrected. The ride PSI was improved to 4.20 which is better than the unground inner lane. This pavement had served for 17 years before grinding and should provide many more years of useful service after this restoration. The cost of grinding for the entire length of the slabs was about $1.55/sq. yd. or only about $0.15 higher than grinding portions of slabs in 1963.

Photographs of a grinding operation, ground pavement and experimental shoulder treatments are shown in the Appendix. Grinding specifications are also included.

APPENDIX

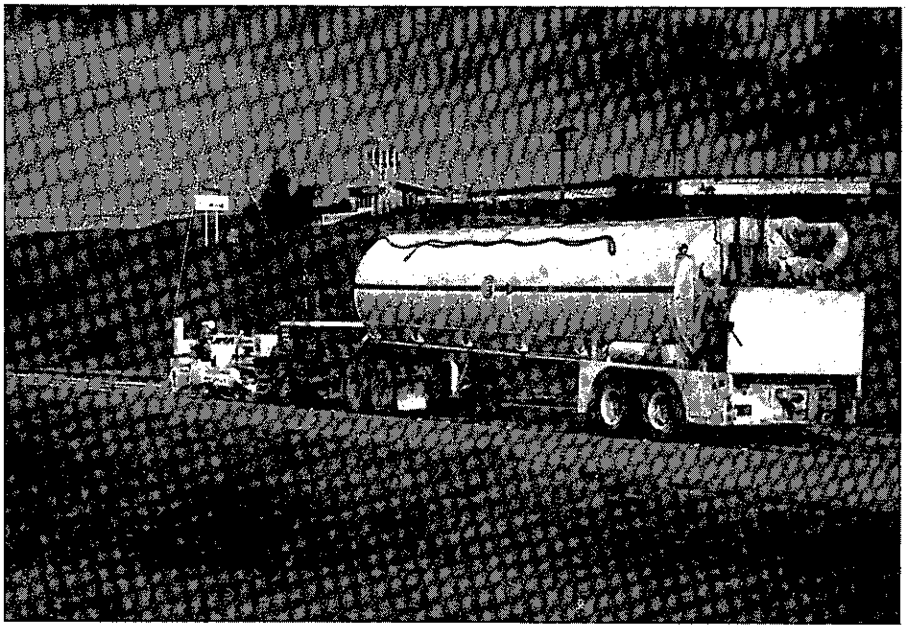


Fig. 1
Grinding equipment with tank for both cooling water and waste water.

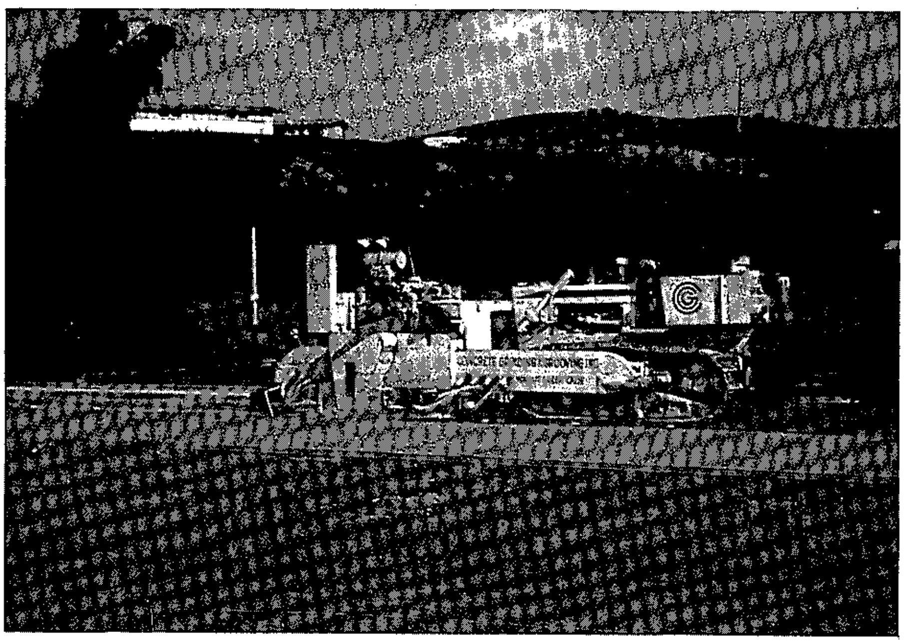


Fig. 2
Grinder in operation.

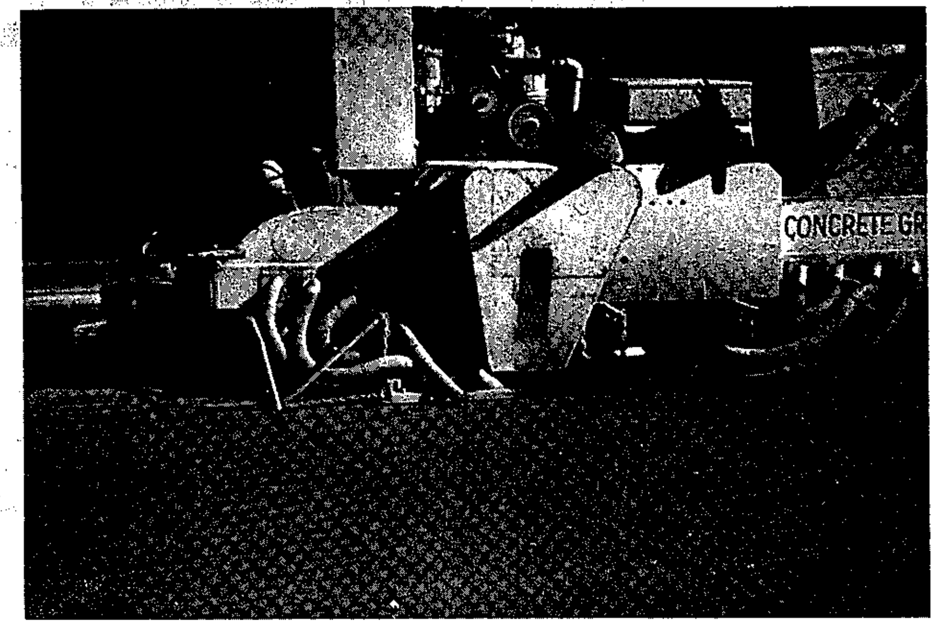


Fig. 3
Vacuum equipment for removing water and residue from grinding.

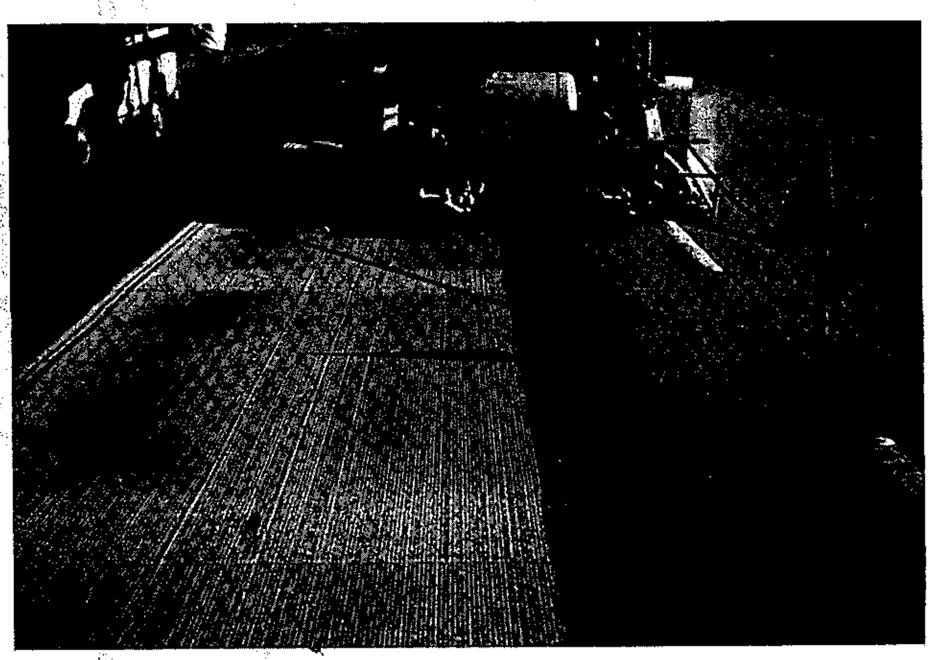


Fig. 4
Last pass of grinder.

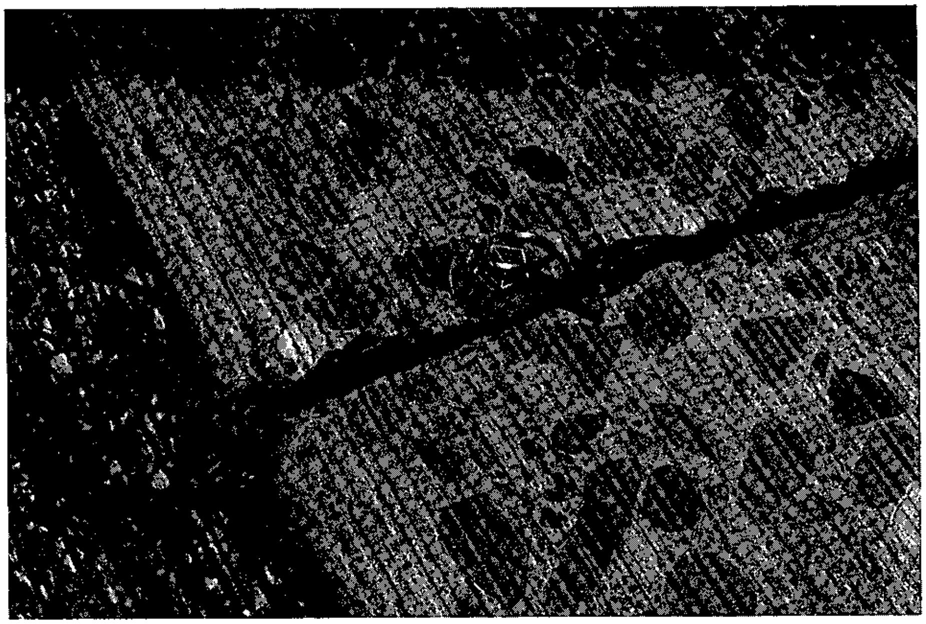


Fig. 5
Grinding across joint formed by steel insert.

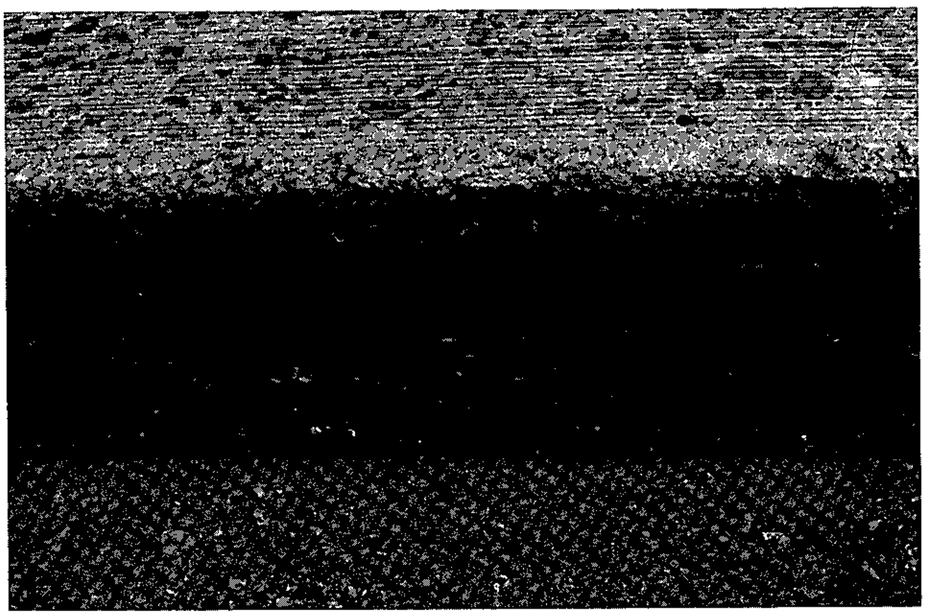


Fig. 6
Portion of shoulder removed to bottom of slab.

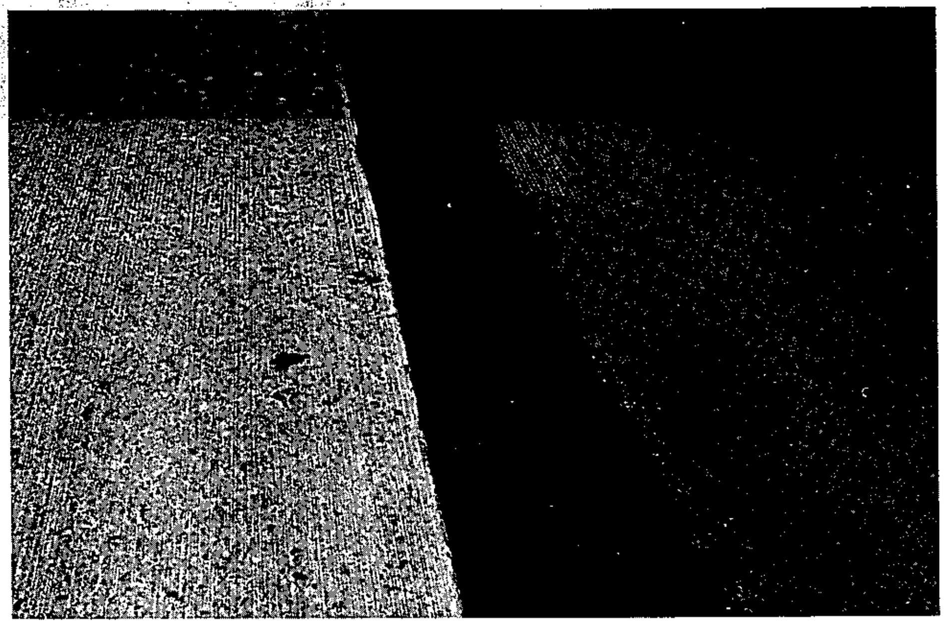


Fig. 7
Shoulder opening ready for backfill.

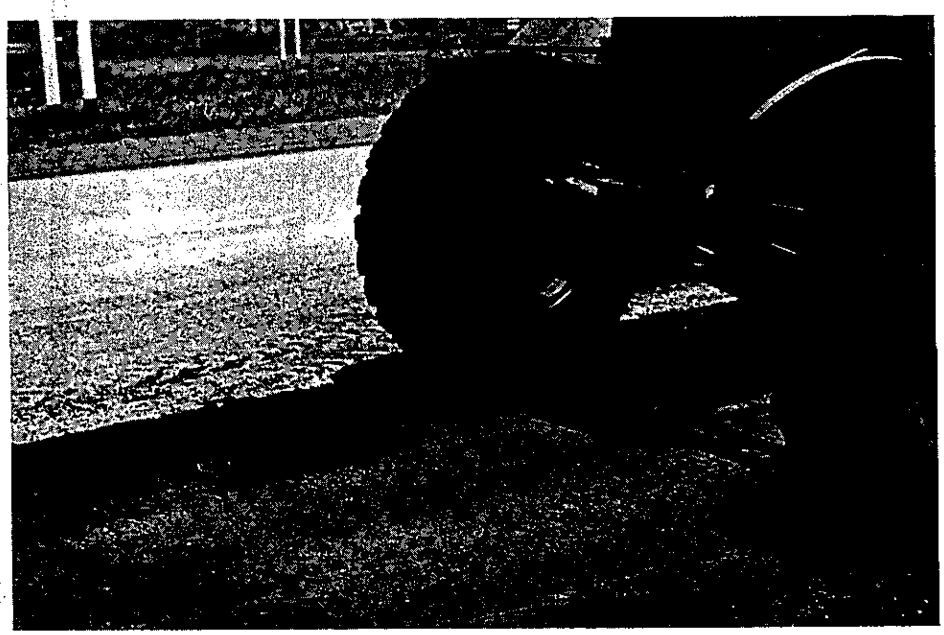


Fig. 8
Wheel rolling of AC (wearing surface
rolled with steel-wheeled roller).

Fig. 9
General view of area with slotted drain pipe.

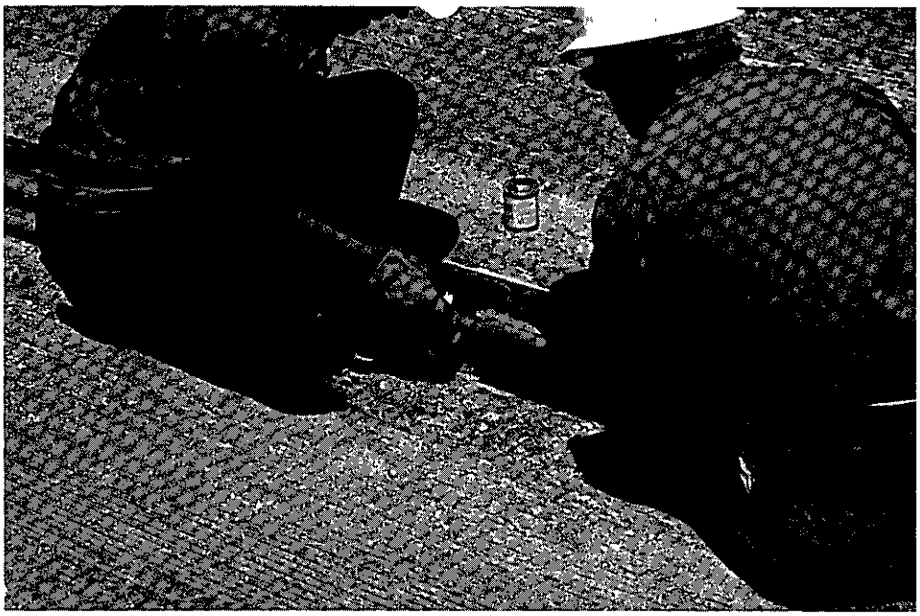


Fig. 10
Lubricating and joining drain pipe.

Fig. 11
Covering pipe with removed shoulder material.

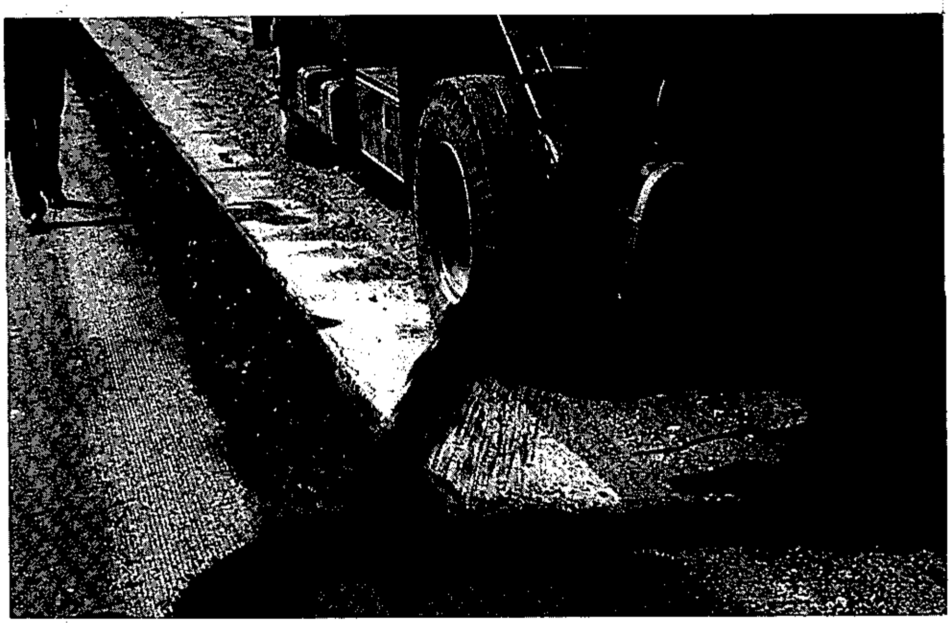


Fig. 12
Replacing AC shoulder over pipe.

SECTION 42

GROOVE AND GRIND PAVEMENT

42-2 GRINDING

42-2.01 **Description.**—This work shall consist of grinding asphalt concrete or portland cement concrete pavement and roadway surfaces of structures as shown on the plans and as specified in these specifications and the special provisions.

42-2.02 **Construction.**—Except on structures, the entire surface area of pavement in locations designated shall be ground until the pavement surface on both sides of all transverse joints and all cracks is in the same plane. After grinding has been completed, the pavement shall conform to the requirements for final finishing as specified in Section 40-1.10, "Final Finishing," except that on existing pavements the first, second, third, and last paragraphs will not apply.

Ground areas on structures shall conform to the requirements in Section 51-1.17, "Finishing Bridge Decks."

Residue from grinding shall be removed from the roadbed by sweeping or washing.

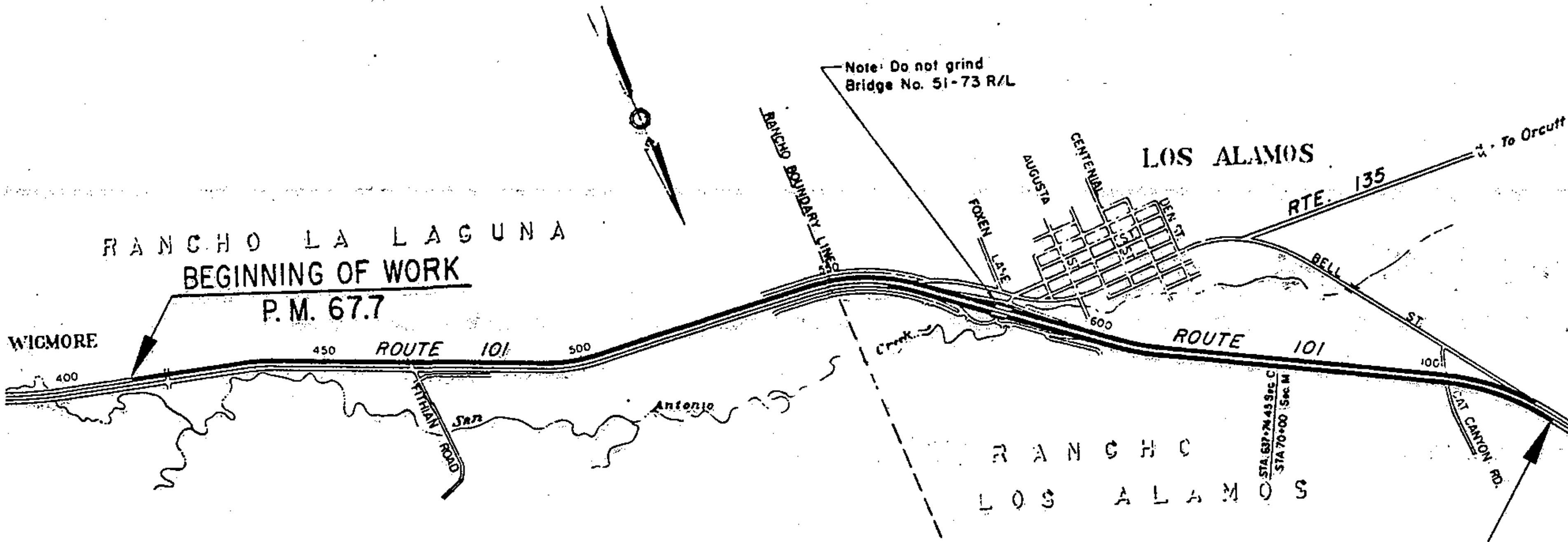
Ground surfaces shall not be smooth or polished and shall have a coefficient of friction of not less than 0.30 as determined by Test Method No. Calif. 342.

Residue from grinding operations shall not be permitted to flow across shoulders or lanes occupied by public traffic or to flow into gutters or other drainage facilities. Solid residue resulting from grinding operations shall be removed from pavement surfaces before such residue is blown by the action of traffic or wind.

The noise level created by the combined grinding operation shall not exceed 86 dbA at a distance of 50 feet at right angles to the direction of travel.

42-2.04 Measurement.—Pavement grinding on existing pavements will be measured by the square yard. The quantity of pavement grinding to be measured for payment will be determined by multiplying lane width by the total length of lane ground.

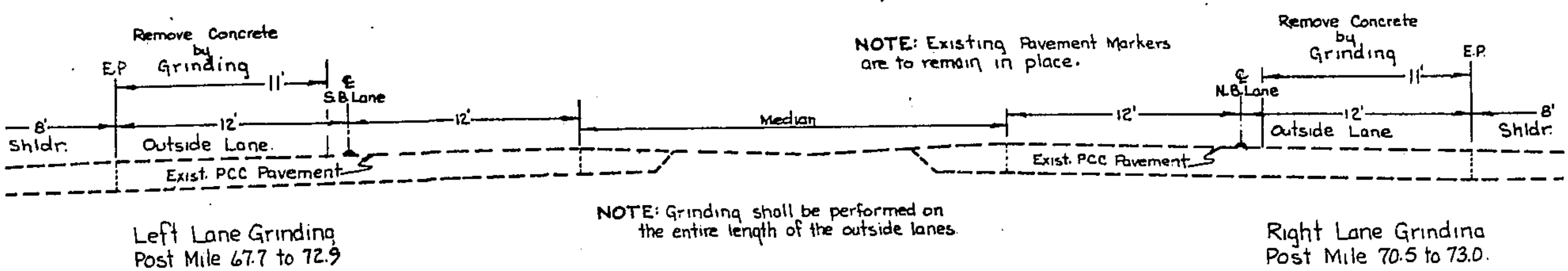
42-2.05 Payment.—The contract price paid per square yard for grind existing concrete pavement shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all work involved in grinding the existing pavement and removing residue, including furnishing water for washing the pavement, as shown on the plans, as specified in these specifications and the special provisions and as directed by the Engineer.



CONCRETE PAVEMENT GRINDING

Location	Width	Sq Yds.
Right Lane P.M. 70.5 to 73.0	12'	17,600
Left Lanes P.M. 67.7 to 72.9	12'	36,608
Less Area of Bridge		
51-73 Right		- 300
51-73 Left		- 300
Total		53,608

NOTE: Existing Pavement Markers are to remain in place.



NOTE: Grinding shall be performed on the entire length of the outside lanes.

TYPICAL CROSS SECTION
Scale: 1" = 4'

SECTION 9. DESCRIPTION OF WORK

The work to be done consists, in general, of grinding the existing pavement as shown on the plans and such other items or details, not mentioned above, that are required by the plans, Standard Specifications, or these special provisions shall be performed, placed, constructed or installed.

10-1.02 GRIND EXISTING CONCRETE PAVEMENT.--Grinding existing portland cement concrete pavement and bridge decks shall conform to the provisions in Section 42-2, "Grinding," of the Standard Specifications and these special provisions.

Grinding shall be performed at the locations shown on plans.

Profilograph sheets of the area to be ground are on file at the District Office, 50 Higuera Street, San Luis Obispo, California.

Residue from grinding operations shall not be permitted to flow across shoulders or lanes occupied by public traffic or to flow into gutters or other drainage facilities. Solid residue resulting from grinding operations shall be removed from pavement surfaces before such residue is blown by the action of traffic or wind.

Residue from grinding operations shall be disposed of outside the highway right of way in accordance with the provisions in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Standard Specifications or shall be disposed of at the disposal sites shown on the plans.

Disposal of residue at sites shown on the plans shall be accomplished by burying the material in pits.

ADDENDUM

This is the fourth report on the research of California's pavement faulting problem. The first report, "California Pavement Faulting Study", January 1970, covered results of field work, where portions of pavement slabs were removed. In some cases, tracer sands had been placed near the joints several weeks prior to pavement removal, and the location of the sand after opening indicated the type of action taking place under the pavement. It was concluded that a heavy load crossing a joint when free water was under the slab caused violent water action and moved loose or erodible material backwards (opposite the traffic direction) and deposited it under the approach slab. This buildup was about equal to the amount of faulting measured on top of the pavement slab at the joint. Major sources of the buildup material were fines from the shoulder and the eroded base.

Report No. 2, "Faulting of Portland Cement Concrete Pavements", was presented at the 51st Annual Meeting of the Highway Research Board in January 1972, and published in HRR 407. Possible solutions to the faulting problem are discussed and details are given of various experimental shoulder treatments which had been placed on construction projects. These treatments were basically to eliminate shoulder fines as a source of faulting buildup, but one experiment, a full width permeable asphalt concrete shoulder, also provided drainage of water from under the pavement. Also reported were results of a laboratory study of lean concrete base, a material which could be placed with a slipform paver using internal vibration. This base was found to have a relatively erosion resistant surface which should eliminate eroded base fines as a source of faulting buildup material.

The third report, "California Trials With Lean Concrete Base (LCB)", was published in October 1975. It covers details of two large-scale field trials of lean concrete base. On one project the cement content was 8%, by weight of the dry aggregate, and on the other, 8.5%. Both projects proved to be very satisfactory, providing greater base stiffness and a more sealed and abrasion resistant surface then normally obtained with cement treated base. Suggestions for LCB specifications are also given. No comparison of the LCB and the CTB performance is included as the service life is yet too short.